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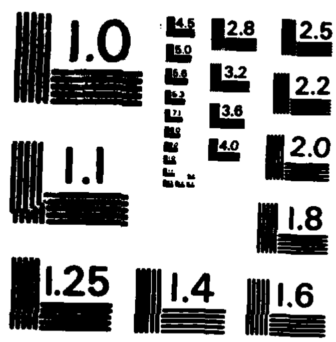

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AIR COMMAND
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STUDENT REPORT

WILL THE USAF NEED GROUND-BASED AIR TRAFFIC CONTROL RADAR IN THE YEAR 2000?

MAJOR GEORGE L. VARN 86-2585

"insights into tomorrow"

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REPORT NUMBER 86-2585

TITLE WILL THE USAF NEED GROUND-BASED AIR TRAFFIC CONTROL RADAR IN THE YEAR 2000?

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Submitted to the faculty in partial fulfillment of
requirements for graduation.

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Advanced technology in military aviation is developing rapidly. The Global Positioning System (GPS) and Microwave Landing System (MLS) will give the pilot precision navigation capability when fully deployed in the 1990s. The Joint Tactical Information Distribution System (JTIDS) will give the pilot the capability to display enemy and friendly aircraft in his area in his cockpit. At the same time, our mobile air traffic control (ATC) radars are aging and need to be replaced. But, with the new technology in the cockpit, it may be more feasible to eliminate ground-based ATC radar and let the pilot do his own ATC from the cockpit. This study examines the feasibility of a cockpit-based ATC system by looking at the requirement for military ATC, specific capabilities that new technologies give the pilot, and human considerations in a cockpit-based ATC system. The study concludes that a cockpit-based ATC system is not feasible and that there will be a need for ground-based ATC radar, at least through the year 2000.

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PREFACE

Advanced technology in military aviation is developing rapidly. By the 1990s, the military pilot will have highly precise navigation capability with the deployment of the Global Positioning System (GPS) and the Microwave Landing System (MLS). The pilot will be able to display enemy and friendly aircraft in his cockpit with the installation of the Joint Tactical Information Distribution System (JTIDS). At the same time, mobile air traffic control (ATC) radars are aging. The newest one will be 20 years old in the 1990s and the oldest will be nearly 40 years old. In short, the USAF needs a new mobile ATC radar. However, if advanced airborne technology enables the pilot to see other aircraft in his area on a cockpit display, why should the Air Force deploy a new mobile ATC radar? Why not avoid this expense and let the pilot perform his own ATC from the cockpit?

This study analyzes the need for a ground-based radar ATC system in the USAF in the year 2000 in light of the new technology. In doing so, the study determines the feasibility of a cockpit-based ATC system as a replacement for the ground-based radar system. Assuming the worst case of a wartime environment and bad weather, the study looks at the present ATC system, analyzes the capabilities of the GPS, MLS, and JTIDS to support a cockpit-based ATC system, and studies the human considerations of workload and safety in a cockpit-based ATC system.

In preparing this study, the author received significant help from many sources. The author wishes to especially acknowledge the help of Col George Frederick, Lt Col Richard Perry, Lt Col Randy Roach, Major Vince DiMattina, and Mr Herb Schall of the Airspace and Air Traffic Services Division at HQ USAF. These gentlemen gave their valuable time to guide the author to the best sources. The author would also like to acknowledge the help he received from Major James Webb of the Air Command and Staff College. Major Webb, a fighter pilot, played a "devil's advocate" role in questioning the author's data and conclusions throughout the study. But most of all the author would like to thank his lovely wife, Laura, and daughter, Mary Lisa, for their patience while he worked on this study.

ABOUT THE AUTHOR

The author is an experienced air traffic control (ATC) officer. He graduated from the ATC Officer Technical School at Keesler AFB, Mississippi in May 1974. He received ratings in the Travis AFB, California Radar Approach Control (RAPCON) and Control Tower prior to graduating from the ATC Officer Training Program (OTP) in July 1975. He completed a RAPCON certification while performing duties as RAPCON Chief Controller and later Chief, ATC Operations for the 4th Tactical Fighter Wing (TFW) at Seymour Johnson AFB, NC from August 1975 to May 1977. He went on to become the Chief, ATC Operations at Thule Air Base, Greenland and at Aviano Air Base, Italy. At Aviano he gained extensive experience in wartime tactical operations using a mobile ATC radar to support fighter operations in NATO Tactical Evaluations and USAF Operational Readiness Inspections. In 1981 Major Varn became the Chief, ATC Training at Shaw AFB, SC where he ran the USAF ATC Officer Training Program during the 363rd TFW's conversion from RF-4 to F-16 aircraft. Then, Major Varn served on the faculty and staff of Squadron Officer School (SOS) at Maxwell AFB, AL. Major Varn's education includes Squadron Officer School and Air Command and Staff College as well as a Master of Public Administration degree from Auburn University.

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REPORT NUMBER 86-2585

AUTHOR(S) MAJOR GEORGE L. VARN, USAF

TITLE WILL THE USAF NEED GROUND-BASED AIR TRAFFIC CONTROL RADAR IN THE YEAR 2000?

I. Purpose: To analyze the need for air traffic control (ATC) ground-based radar in the year 2000 by looking at the feasibility of letting the pilot do his own ATC from the cockpit.

II. Problem: Our present ground-based mobile ATC radars are old and need to be replaced. However, the latest aviation technological advancements will give the pilot the capability to conduct highly precise navigation without assistance from a ground-based controller as well as the capability to display other aircraft in his area in the cockpit. This may give the pilot the capability to perform his own ATC from the cockpit, thus avoiding the need to replace our mobile ATC radars.

III. Data: This study analyzes the possibility of the pilot performing his own ATC in a wartime European theater with the possibility of flying in bad weather and contending with jamming and direct enemy attack. The requirement for military ATC exists because there is a need to separate and sequence aircraft departing and returning to home bases from the battle area in wartime. The present ground-based ATC system uses radar which is independent of equipment in the aircraft. Radar displays all aircraft within its range independent of any airborne equipment.

CONTINUED

Radar can give our Army Short Range Air Defense System current information so it can distinguish between enemy and friendly aircraft in its effort to defend our air bases from enemy attack. However, our current radars are vulnerable to enemy attack and jamming because they are old and because they are located close to our bases' runways. An analysis of three major military aviation technological advancements shows that the Joint Tactical Information Distribution System (JTIDS) may be the best candidate to enable the pilot to do his own ATC from the cockpit and eliminate the need to replace our present ground-based radars. The technological analysis is limited to three systems because these systems are the most visible advances in military aviation technology and because of the ever-changing and classified nature of military technology. The Global Positioning System and the Microwave Landing System are not designed to give the pilot the information he needs to do his own ATC. But JTIDS gives the pilot the location of other friendly JTIDS equipped aircraft which is the information he needs to perform ATC from the cockpit. However, although it seems technologically possible, a cockpit-based ATC system using JTIDS is not feasible. For a cockpit-based system to work, JTIDS terminals would have to be installed in every friendly aircraft that might fly into bases that use such a system. This would be a highly expensive and therefore prohibitive adventure. Even if the USAF installed terminals in every aircraft, surely battle damage would render many inoperable without impairing the pilot's ability to fly the aircraft. It appears that a cockpit-based ATC system would have problems from a human factors viewpoint as well. Pilot workload while approaching to land at an air base is already high. Adding the stress and workload of performing all his own ATC with no help from a ground-based radar to the workload of contending with the enemy threat, battle damage, and bad weather could be unbearable for the pilot. At the least, this high workload would appear to negatively affect flying safety which already is tough to maintain in the busy airspace surrounding our peacetime air bases. But with the added stress of war and bad weather, it appears that a cockpit-based ATC system would only add to the chance of pilot error and, therefore, significantly reduce the ability of our pilots to return safely from battle.

CONTINUED

IV. Conclusions: It appears that, although ground-based ATC radar has its limitations, it still provides the best capability to safely recover aircraft in war. Although the GPS, MLS, and JTIDS appear attractive, they would be too expensive and impractical to use as bases for a cockpit-based ATC system. It also appears that human considerations for workload and safety do not recommend a cockpit-based ATC system. Therefore, a cockpit-based ATC system would not be a sound replacement to eliminate the shortcomings of the present ATC system in war. The USAF will continue to need a ground-based radar ATC system in the year 2000.

V. Recommendations: The USAF should pursue research and development of a new, highly mobile, long-range ATC radar that will be jam and electro magnetic pulse resistant. When operational, the radar should be employed in remote rear areas dispersed from forward operating bases to heighten survivability. At the same time, the USAF should develop procedures to use future cockpit technology for the benefit of the pilot and controller. Controllers might be able to better expedite traffic in bad weather and war for those aircraft that are properly equipped with cockpit display of other aircraft in the terminal area.

Chapter One

INTRODUCTION

BACKGROUND/SIGNIFICANCE

Advanced technology in military aviation is developing rapidly. The USAF is researching and developing many capabilities unheard of before--aircraft that fly sideways, cockpit systems that respond to voice commands, artificial intelligence that keeps an aircraft flying despite a damaged aileron. In particular, there have been major advances in aircraft navigation and tactical information systems which the Air Force will deploy in the late 1980s and 1990s. For example, the Global Positioning System (GPS) will enable a pilot to determine his position in any weather anywhere in the world. When combined with a data link system to enable aircraft to transmit their position to each other, GPS could give pilots the ability to see all other aircraft equipped with GPS within a certain airspace area. Similarly, the Joint Tactical Information Distribution System (JTIDS) enables the pilot to see not only enemy aircraft but also friendly aircraft on a display in his cockpit. In short, in the near future, advanced technology will give the pilot unprecedented access to air traffic control (ATC) and tactical information. Some might conclude that this information, displayed in the correct manner in the cockpit, will eventually enable the pilot to separate himself from and sequence himself in with other aircraft without the requirement for ground-based air traffic control (ATC) assistance.

At the same time advanced technology is making rapid improvements in airborne aviation systems, our USAF ground-based mobile ATC radars need to be replaced. Many of the radars are Korean War vintage systems, and our most recently deployed mobile radar will be more than 20 years old by the year 2000. Therefore, the USAF is studying the possibility of researching and developing a new mobile ATC radar to be deployed in the 1990s.

The question which arises with these new technological capabilities is one of need. If advanced airborne aviation technology gives the pilot the information he needs to separate and sequence himself with other aircraft, that is, to perform the primary functions of ATC, then why should the Air Force deploy a new mobile ATC radar? Why not let the pilot do all his own ATC from the cockpit and eliminate the need for an expensive ground-based radar ATC system?

This study will analyze the need for a ground-based radar ATC system in the USAF in the year 2000 in light of the new technology. In doing so, this study will determine the feasibility of the pilot to perform ATC in the terminal area from the cockpit without a ground-based radar ATC system.

ASSUMPTIONS/LIMITATIONS

A. The worst case condition for analyzing the possibility of the pilot performing his own ATC will be considered to include

(1) flying in the wartime European theater with the possibility of rapid degradation of aircraft systems through jamming and direct enemy attack, and

(2) flying in Instrument Flight Rules (IFR) weather.

B. The study was not able to look at all technology because of the everchanging and classified nature of military technology. For example, the study does not examine the possibilities of using space-based radar to improve ATC from the ground or from the cockpit. Therefore, the study limits the technological portion to the most visible advances in military aviation technology--the GPS, JTIDS, and the Microwave Landing System (MLS). Through a review of the literature, it seems that these systems offer the greatest possibilities for the pilot to perform his own ATC from the cockpit.

C. Through a review of the literature, the study found no previous work on this precise subject. Most studies that dealt with advanced aviation technology were based on continuing a ground-based ATC system but with more functions delegated to the pilot. The study found no work that included analyses of pilot human factors in a cockpit-based ATC system. Therefore, the study's conclusions will be based on logical extensions of studies of pilot workload, fatigue, and safety in the current ATC system.

OBJECTIVES OF THIS STUDY

To analyze whether or not the pilot can perform ATC in the terminal area from the cockpit, this study will first look at the requirements, capabilities, and interoperability of the present ground-based system. Then, it will analyze the technological possibilities for the pilot to assume full responsibility for terminal radar ATC from the cockpit in a wartime environment.

The study of the technology will analyze the capabilities of the GPS, JTIDS, and MLS to safely recover aircraft without ground-based radar ATC. The technological analysis will also study the interoperability of these systems among US and Allied Forces. Next, the study will look at the human possibilities for the pilot to perform ATC functions from the cockpit in a wartime environment. The study will look at the possible effects of a cockpit-based ATC system on pilot workload and flying safety. Finally, the study will draw conclusions and make recommendations about the future of ground-based radar ATC in the USAF.

Chapter Two

REQUIREMENT FOR ATC--THE PRESENT SYSTEM

INTRODUCTION

Before analyzing the capability of the pilot to perform his own ATC functions from the cockpit, it is necessary to look at the requirement for military air traffic control. In addition to determining the requirement for military ATC, this chapter will describe the present system by looking at its components and capabilities. Again, the setting is the wartime European theater with the possibility of widespread jamming, direct enemy attack, and bad weather.

THE REQUIREMENT

Federal Aviation Administration (FAA) Handbook 7110.65, Air Traffic Control, authorizes the military services to perform ATC services within airspace delegated to military bases. In Europe, the US Air Force performs ATC within areas delegated to it under various status of forces agreements with each nation (44:3). The FAA Handbook further describes the basic requirements for any ATC unit as separation and sequencing (44:7). Therefore, present day military ATC units must separate aircraft from each other as well as specify the sequence in which aircraft will land. However, separating aircraft is not as simple as it may sound.

There are three types of separation: longitudinal, lateral, and vertical. The military controller uses these types of separation to help a wide range of aircraft safely land. At any time in a normal peacetime environment, there may be slow moving helicopters, heavy cargo aircraft, and high performance fighter aircraft maneuvering in the same airspace. The military controller must separate these varying types of aircraft with varying distances. For example, when landing behind a C-5, a fighter aircraft must remain at least ten miles from the larger aircraft to avoid the air turbulence created by the C-5. However, when landing behind another fighter aircraft not in the same formation, the pilot needs only three miles separation (44:173).

In addition to separating aircraft, the military controller must sequence aircraft. The controller must determine the order in which aircraft will land or depart. Normally, aircraft land on a first-come, first-serve basis, that is, in the order in which they arrive in the controller's airspace (44:143). However, many variables enter the picture to change this orderly environment. For example, it may be more efficient to land several fast fighter aircraft ahead of a slow moving C-5 even if the C-5 pilot contacted the ATC facility first.. However, if the C-5 had just completed a long overseas mission and the fighter aircraft were training in the local area, the controller may let the C-5 land even if the fighter aircraft were in the area before the C-5. Of course, a more important exception to the first-come, first-served basis of sequencing is an aircraft emergency. The controller will extend first priority to emergency aircraft over all other aircraft (44:143). If there are several different emergencies, the controller will base sequencing on the seriousness of each emergency.

In peacetime, military controllers perform these operations in a fairly stable, predictable environment. But in the ever-changing scenario of wartime, the tasks of separation and sequencing become much more complex. According to a study performed by the Mitre Corporation for the Air Force Systems Command's Electronic Systems Division, wartime air traffic control (ATC) operations in the future in Europe will require flexibility and real-time management. There will be a wide variety of aircraft that require ATC. They will employ stealth techniques to deny radar coverage to the enemy. Aircraft will have short takeoff and landing capability so they can use unprepared terrain (41:3). Aircraft from the US Army, Navy, and Marine Corps as well as the Air Force will interact along with aircraft from our NATO allies in the same European airspace. Clustered and dispersed runways will result in overlapping areas of approach and departure paths. Bases will change rapidly relative to availability and supportability for aircraft requiring service. Preplanned information will be available but will change dynamically to match the operational situation. Navigation systems will permit more flexible routes to and from bases, not following fixed structures or entry points. With more entry points and flexible routing there will be a greater need for separation and sequencing. Because of ad hoc bases, extensive publication of procedures will not be available for prestudy by pilots. Greater real-time flight information will have to be given to aircraft on base location and configurations. Control operations will have to direct aircraft to appropriate bases within an area, perhaps to covert bases or areas not previously used for landings. Takeoff flow control and location of loitering positions will be dynamic to account for battle damage to the primary landing bases and for the need to be unpredictable (41:5).

Military ATC facilities may have to control several bases, each with an hourly required launched recovery rate of 70 to 100 missions. Aircraft will recover with battle damage in a hostile environment filled with electronic countermeasures (ECM), electromagnetic pulse (EMP) and direct armed attack from the enemy. ATC facilities will need to work closely with air defense sites to ensure the safe passage of our aircraft through our own local air defenses. This will be especially important in an environment in which bases change rapidly and local air defense sites cannot recognize friendly aircraft. (41:13)

THE PRESENT SYSTEM

Our present ATC system has several components with various capabilities and limitations to meet these requirements. This study will restrict itself primarily to the radar component which separates and sequences aircraft for approach to land on the runway controlled by the control tower. Military controllers normally control airspace within 30 to 50 miles of the primary base and up to about 10,000 feet.

Our present radar system has two modes: primary and secondary. The primary mode, with a range of 60 nautical miles, provides an independent system. This means it can display all aircraft within its range (with varying altitude restrictions) with a high level of assurance and independent of any equipment on the aircraft (49:2). This gives the controller the flexibility to serve any type aircraft, no matter what kind of onboard equipment it has. The secondary mode, with a range of 200 nautical miles, is a dependent system. This means it depends on equipment in the aircraft to enable the controller to display information for identification and altitude on the radar scope without relying solely on voice communication for the information. Military controllers normally use the primary and secondary modes simultaneously to provide positive position correlation (59).

Although the USAF has several fixed radars in Europe, it relies primarily on 25 MPN-14 and 10 TPN-19 mobile radars. The MPN-14 is a derivative of the old CPN-4, a Korean War vintage radar first built in 1951. The TPN-19 is a newer 1970s vintage radar built under a contract first let in 1969. To buy a new TPN-19 today would cost the Air Force about $4.6 million (57). Using a new procedure called Aircraft Surge Launch and Recovery (ASLAR), controllers using either of these radars can separate and sequence a maximum of 80 fighter aircraft per hour (10:6).

Another capability of the present ground-based radar system is support of Short Range Air Defense (SHORAD) which is provided by the US Army. The Army is responsible for the SHORAD of US air bases in Europe. The Army's SHORAD provides air defense against low-flying terrain-hugging aircraft operating below the normal air defense missile system's capabilities. When all other defense systems fail and enemy aircraft penetrate the normal air defenses, the Army uses Chaparral, Vulcan, and Redeye/Stinger artillery and missile systems in the immediate vicinity of a base. However, to distinguish enemy aircraft from friendly aircraft the Army must have more information than it would ordinarily have. According to Army Colonel Domenic Rocco, the 108th Air Defense Artillery (ADA) Brigade in Europe uses a modified version of the manual SHORAD control system as a frame of reference in dealing with the problem of sorting friendly from hostile aircraft. The modified version of transmitting early warning to the 108th ADA Brigade fire units begins at the defended base's radar approach control ATC unit. At all defended US air bases, an Air Force air traffic controller broadcasts aircraft position data for both friendly and unknown aircraft directly to the SHORAD fire units (19:24). The benefit of using the ATC radar for early warning is that its 60 mile range enhances the short range of the Army's ADA radars. Additionally, air traffic controllers are in constant voice communication with other friendly aircraft that may not be detected by either the ATC or the Army's ADA radar. The Army prefers early warning from the ATC radar units to early warning from Hawk missile units because the ATC radar early warning is localized. That is, the ATC radar unit can give the SHORAD units more specific information because each ATC radar unit is concerned about only one or two bases (19:26).

However, the present ground-based radar system has its limitations. For example, to achieve the maximum 80 fighter aircraft per hour recovery rate, controllers must rely partially on equipment in each aircraft. To achieve the maximum rate, controllers must reduce separation between flights from three nautical miles to 9000 feet. To do this, controllers authorize pilots to use their airborne radars to maintain longitudinal separation from the flight ahead. Controllers also have the pilots use onboard navigation equipment to maintain course guidance which relieves the controller from providing course guidance using labor intensive radar separation methods. So, in a real wartime recovery situation, if the numbers really are as high as 80 fighters per hour or more, the controller must rely partially on airborne equipment, despite the independence of the primary radar system (10:5).

Closely related to this limitation is a limitation on interoperability. When working with large numbers of aircraft, controllers must use their secondary radar in conjunction with the primary radar to help identify aircraft and distinguish between friend and foe. There are plans to adopt a secondary radar system fully interoperable between the US and its NATO allies in Europe, but the current systems are not interoperable.

As a result, if a war happened today, NATO pilots may find it as hard to return home safely as it is to penetrate the Warsaw Pact's defenses (16:80).

Another limitation is the vulnerability of present radars to enemy attack. According to the Mitre Corporation study of terminal area air traffic control using an automated launch and recovery system, present radars are very vulnerable to electronic countermeasures and jamming that can blot whole sections of the controller's radar scope. Even without jamming the primary radar emission from the ground, the enemy can jam the secondary radar signal by jamming aircraft systems (41:12). But more importantly, the radars' emissions from the ground, coupled with the radars' close proximity to runways, enable enemy aircraft to pinpoint locations of runways and aircraft concentrations. Finally, the radars' close proximity to runways makes it vulnerable to collateral damage wrought by the enemy on friendly runways and aircraft. As a result, unless there is redundancy in the system, if the ATC radar is destroyed, no ATC services will be available to our own aircraft (41:11).

CONCLUSIONS

In conclusion, there is a valid requirement for the air traffic control services of separation and sequencing for military aircraft in a rapidly changing wartime environment. The present system is ground-based and relies primarily on controllers sitting at scopes using mobile radars to give them the information they need to separate and sequence aircraft. Controllers using the present system can control any type aircraft because of the independent nature of the primary radar system. Controllers using present radars and airborne equipment can launch and recover as many as 80 aircraft per hour. Controllers can also provide a valuable early warning service to the Army's air defense units and therefore protect our aircraft from our own defenses. But our present ground-based radar controllers face some severe limitations in wartime. Their maximum recovery rate is still dependent on the reliability of equipment in the aircraft and their secondary radar is not interoperable with our NATO allies' aircraft systems. But most importantly, present radars are extremely vulnerable to enemy attack, either through electronic jamming or through collateral damage wrought by the enemy on our runways and aircraft.

Chapter Three

TECHNOLOGY--DOES THE PILOT HAVE THE TOOLS TO PERFORM HIS OWN ATC FROM THE COCKPIT?

INTRODUCTION

Since the present ground-based system has so many shortcomings, is there not a better way to separate and sequence air traffic in the military? Surely, in an age when the US can send men to the Moon, regularly launch space shuttles with crews of seven to orbit the Earth, and take snap shots of the outer planets of the Solar System, the US can construct the technology to separate and sequence aircraft in the atmosphere. In fact, space-age technology is already giving the Air Force several systems that may significantly improve its ability to safely recover aircraft in a wartime environment. Three such systems are the Navstar Global Positioning System (GPS), the Microwave Landing System (MLS), and the Joint Tactical Information Distribution System (JTIDS). This chapter will analyze each system's components and capabilities, interoperability with our NATO allies' systems, and specific capability to support a cockpit-based ATC system. Finally, this chapter will conclude with some overall observations about the technological practicality of a cockpit-based ATC system.

NAVSTAR GPS

According to the GPS NAVSTAR User's Overview,

> The Navstar GPS was developed to provide highly precise position, velocity and time information to users. The GPS is designed to provide present and future generation host vehicles with this high-quality global navigation capability anywhere and at any time (34:2).

According to the Users' Overview, the Department of Defense and the Department of Transportation intend to use the GPS to replace all the currently less accurate navigation systems such as TACAN, LORAN-C, OMEGA, and VOR/DME (34:2).

The GPS is a space-based radio positioning, navigation, and time-transfer system. It is composed of three systems as Figure 1 indicates: Space, Control, and User. When fully operational, the Space segment will be composed of 18 satellites in six orbital planes. The satellites will operate in circular orbits 10,900 nautical miles high. Precise spacing of the satellites will be arranged so that at least four satellites will be in view to a user, thereby ensuring worldwide coverage (34:2). Including three active spare satellites, the Space segment will cost the US $1.2 billion (49:2).

The Control Segment will include several monitor stations and ground antennas located throughout the world. The monitor stations will use a GPS receiver to track all satellites in view and therefore accumulate ranging data from the satellite signals. The Master Control Station in Colorado Springs, Colorado will process the information from the monitor stations to determine satellite orbits and to update the navigation message of each satellite. Ground antennas will transmit the updated information to the satellites (34:2).

The User Segment is a passive system consisting of receivers carried on various vehicles such as tanks, aircraft, ships at sea, and troops, as Figure 1 shows. Each receiver, using data transmitted by the satellites, will derive navigation and time information for local use (34:2). The cost of each receiver the Air Force intends to use in F-15s and F-16s is $66,000 (60).

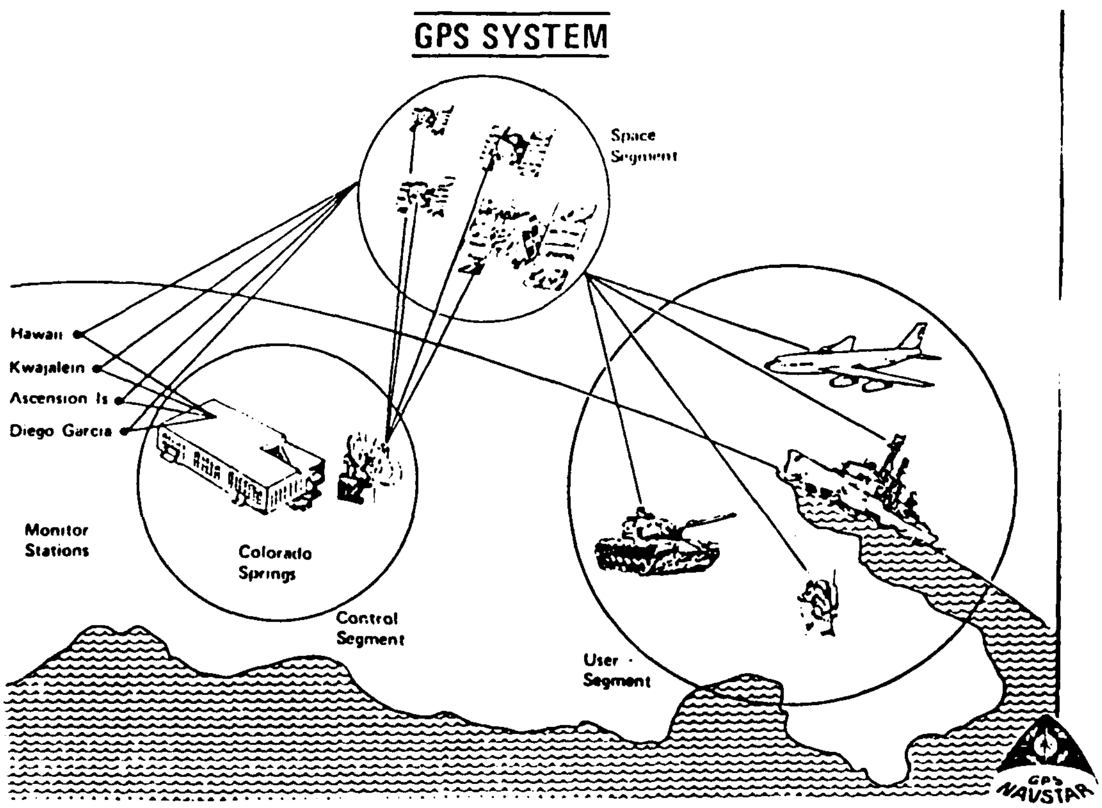

Figure 1. GPS System (34:3)

GPS is an interoperable, survivable system which has many military applications as Figure 2 describes. In air operations, GPS can streamline enroute and terminal navigation, thereby reducing flight times and fuel consumption. Since GPS allows the use of a common grid, all aspects of airborne, ground, and seaborne interoperability are greatly improved. These interoperability aspects include close air support, rendezvous, multi-force command and control, pinpoint cargo drop operations, and search and rescue (34:8). In addition to being interoperable among US forces, GPS will be interoperable among most NATO nations' forces. In 1978, 10 NATO nations signed a Memorandum of Understanding for participation in the development of GPS. Plans for interoperability include standardization of user equipment and antenna studies and trials (34:20). But most importantly, the GPS will be a highly survivable system. To guard against attacks on the satellites, the GPS satellites will be placed in a very high orbit, spaced well apart, and include some redundancy with three spare satellites. To guard against jamming, the signals will be encrypted and spread over a spectrum of frequencies. This makes it much more difficult, although not impossible, to jam the signals (34:4).

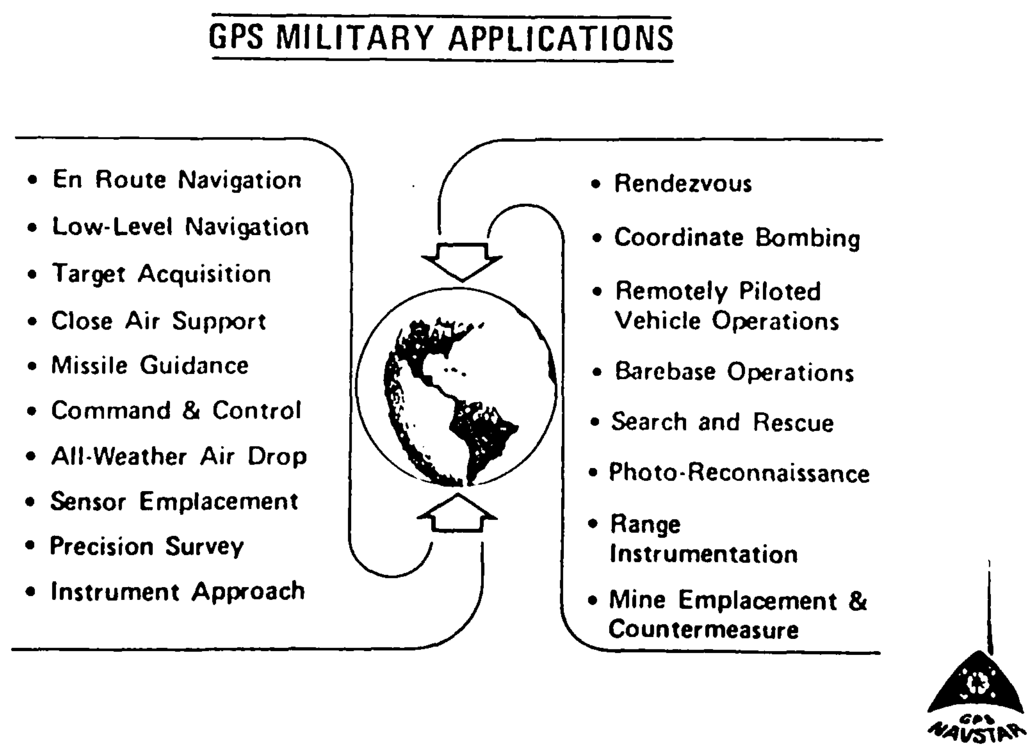

Figure 2. GPS Military Applications (34:9)

But can the GPS enable the pilot to perform his own air traffic control from the cockpit? According to Lieutenant Colonel Jim Brown of the HQ USAF GPS Operational Phase-In Team, the GPS as currently designed cannot provide the capability to the pilot to perform his own ATC. Since the user equipment consists only of a passive receiver, currently the satellites will only enable the pilot to display his own position with respect to known geographical landmarks, not to other aircraft. To separate from and sequence himself with other aircraft, the pilot must know the position of other aircraft. But to display other aircraft positions, the GPS will have to be augmented with an up/down link system. All aircraft would have to be outfitted with transmitters to give other aircraft, through the GPS system, their relative positions. Although this is technically possible it would be financially burdensome (50:2).

Another problem is the fact that all aircraft that may fly into military airspace would have to be outfitted with the GPS. This includes all fighters, cargo aircraft, helicopters, and any other aircraft from all US and Allied services. Although there are plans to install GPS receivers in most US aircraft, according to Colonel Eric Wheaton, Chief of the GPS Operational Phase-in Team, "equipping everyone is technically possible but not feasible" (60). Therefore, even if the US developed a system that gave the pilot a display of other aircraft locations, the display would not show all aircraft in the airspace because all aircraft will not be GPS equipped.

MICROWAVE LANDING SYSTEM (MLS)

The MLS is a precision final approach aid which may replace our current precision aids, the Instrument Landing System (ILS) and Precision Approach Radar (PAR). This means the MLS is designed to give guidance to aircraft on the final approach from a maximum of 20 nautical miles from the runway to landing (47:1). As Figure 3 shows, the MLS is composed of three components: the azimuth antenna at the departure end of the runway, an elevation antenna at the approach end of the runway, and a back azimuth antenna at the approach end of the runway (47:2).

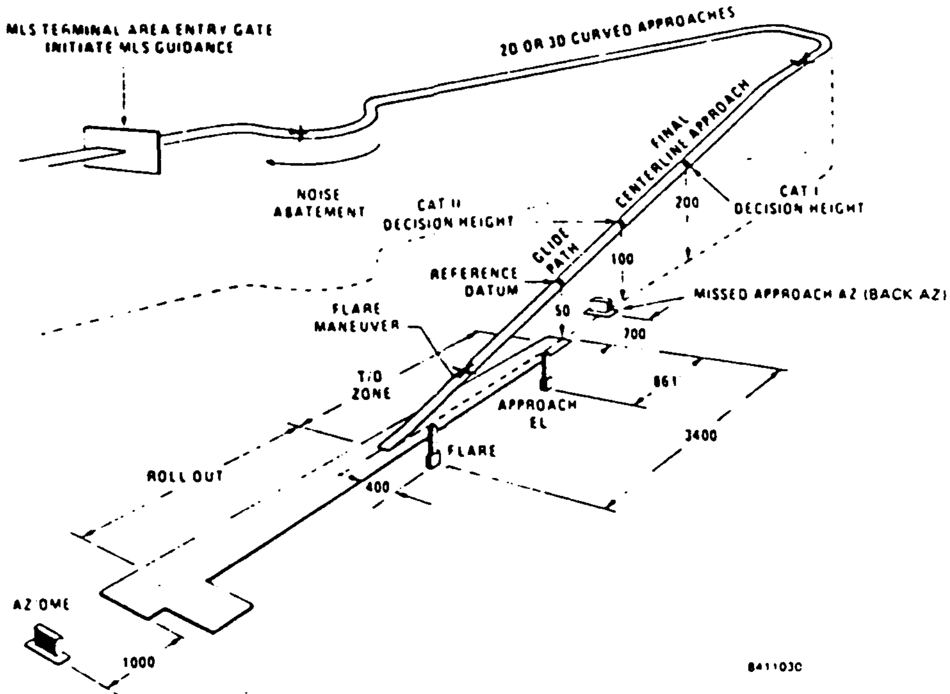

Figure 3. MLS Components Located on the Airport (47:2)

Each component provides course or elevation guidance within the coverage areas shown in Figure 4. The azimuth antenna provides course guidance to aircraft approaching the runway within 40 degrees either side of the extended runway centerline out to 20 nautical miles from the approach end. The elevation antenna provides glidepath coverage within the azimuth scan up to 15 degrees or 20,000 feet. The back azimuth antenna provides course guidance for missed approaches or departures out to seven nautical miles from the departure end of the runway. Aircraft use the MLS components by receiving information from them through a data link to a passive receiver in the aircraft. In other words the aircraft's MLS equipment, similar to the GPS' user equipment is a passive receive only system (47:3).

Costs for the components are about $700,000 for all the ground systems after installation and $12,000 to $15,000 for each aircraft receiver (47:7).

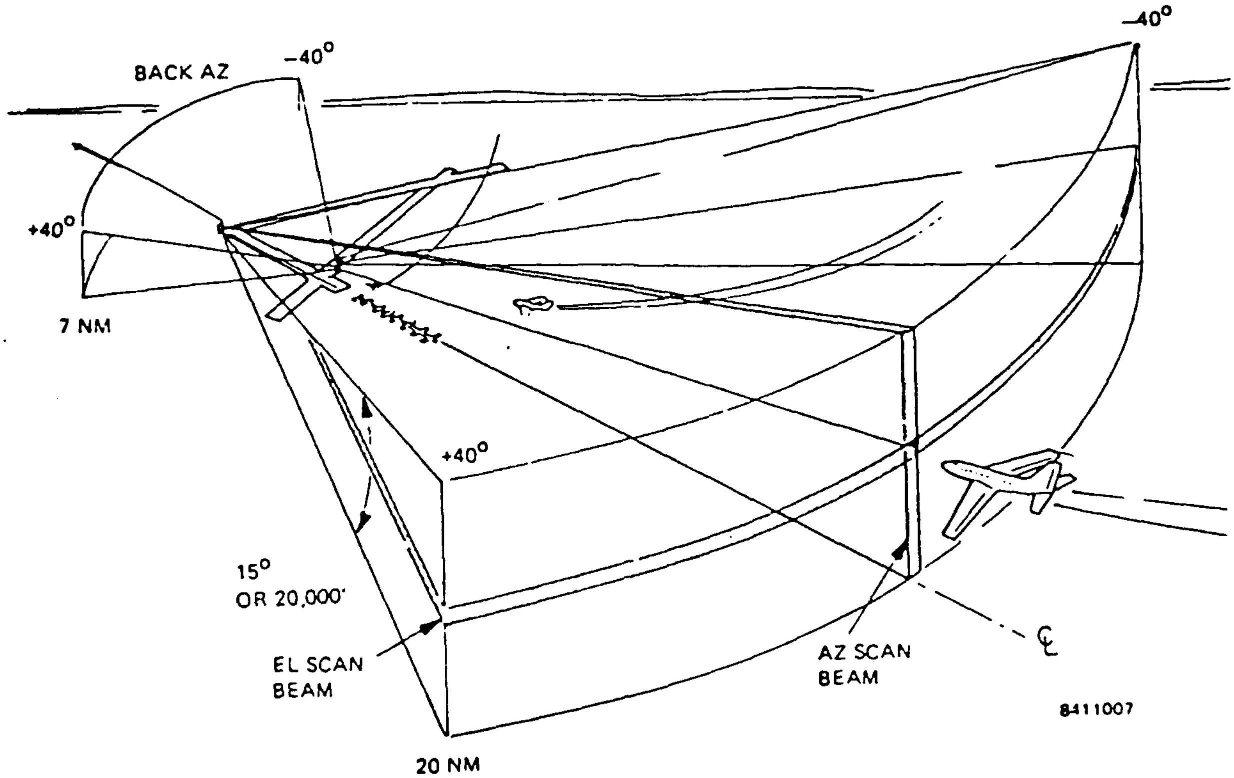

Figure 4. Volume Coverage Afforded by MLS (47:2)

Because of its high precision signal, wide range of coverage, and interoperability, MLS has many capabilities. The precision signal gives pilots the capability to conduct approaches to runways possibly even when the visibility is zero! The wide range of coverage gives the pilot the ability to fly a curved approach to the runway from any point within the coverage. This will enable pilots to fly shorter, steeper final approach paths and possibly avoid enemy ground fire close to friendly bases. Shorter approaches from higher altitudes will also reduce fuel consumption by reducing flying time at lower altitudes in the vicinity of the recovery base (56). Furthermore, although not final today, as early as 1972, NATO adopted a standard MLS system for use with all NATO aircraft. Therefore, when installed, the MLS should be interoperable at least among our NATO allies.

But can the MLS enable the pilot to conduct his own ATC from the cockpit? Although MLS eliminates the need for a radar final controller, the answer to this question is no for several reasons. First, the aircraft equipment is passive, receive only. The MLS only tells the pilot where his own aircraft is in relation to the extended runway center line. Like the GPS equipment, it does not tell the pilot where other aircraft are in relation to the runway. To do this, additional equipment would have to be installed in the aircraft and on the ground and this would significantly increase costs. Plans to make such equipment do not exist. But even if such equipment existed, the MLS antennas do not provide enough coverage to show the pilot all other aircraft he would need to separate himself from and sequence himself with. The coverage would have to be extended well beyond 20 nautical miles and completely around the runway to show all aircraft that would be factors for the pilot. Also, the review of the literature revealed no extensive plans to make the MLS invulnerable to enemy attack, either through electronic jamming or direct attack. Its location close to the runway makes the MLS highly vulnerable to collateral damage from enemy attacks on the runway. Finally, even if all the previous problems could be overcome, there exists a problem similar to one of the GPS' problems. For the pilot to be able to display all aircraft that may affect his safe recovery, every aircraft in the area would have to have operable MLS equipment. If only a few aircraft did not have the equipment, a significant safety problem would exist.

JOINT TACTICAL INFORMATION DISTRIBUTION SYSTEM (JTIDS)

JTIDS is a jam resistant secure means of communicating tactical information in the form of data or voice by use of individual computer terminals. It provides identification of participating units and relative positioning of users with respect to air tracks, surface targets, and navigation checkpoints. This gives a top-down picture of the battlefield with all JTIDS users and sensor-derived tracks and targets displayed in their current location on the displays of command and control facilities and on the displays of fighter aircraft (38:4).

JTIDS components are all participating units that have JTIDS terminals. Participating units can be any radar or other sensor such as air defense radars, E-3A aircraft, and any other aircraft as Figure 5 shows. Participating units transmit and receive tactical information to and from each other on a real-time basis. Therefore, a fighter aircraft going to or returning from battle can receive information about enemy air tracks, targets, and friendly aircraft while transmitting his position to all other JTIDS terminals within his net. Since the only components of a JTIDS net are the terminals of the participating units, the net is virtually nodeless. There is no single component through which all information must be filtered and the loss of which will destroy the net. In other words a ground-based command and control (C2) unit could be destroyed without crippling the rest of the net in which it participated. The only loss to the net would be the information the C2 unit had been transmitting to the net (43:14). The terminals use the principle of Time Division Multiple Access (TDMA) to exchange information. Users are given specific time slots to transmit information to other users who are listening. (See Figure 5) There are 128 time slots per second on a net. A user with much information to distribute (such as an E-3A) might be given many time slots per second. However, a fighter aircraft, which is predominantly a receiver of the information, might be given one time slot every 12 seconds to transmit its position and status. Therefore, depending on how often information needs to be updated, the number of participating units in a net is nearly unlimited (38:4).

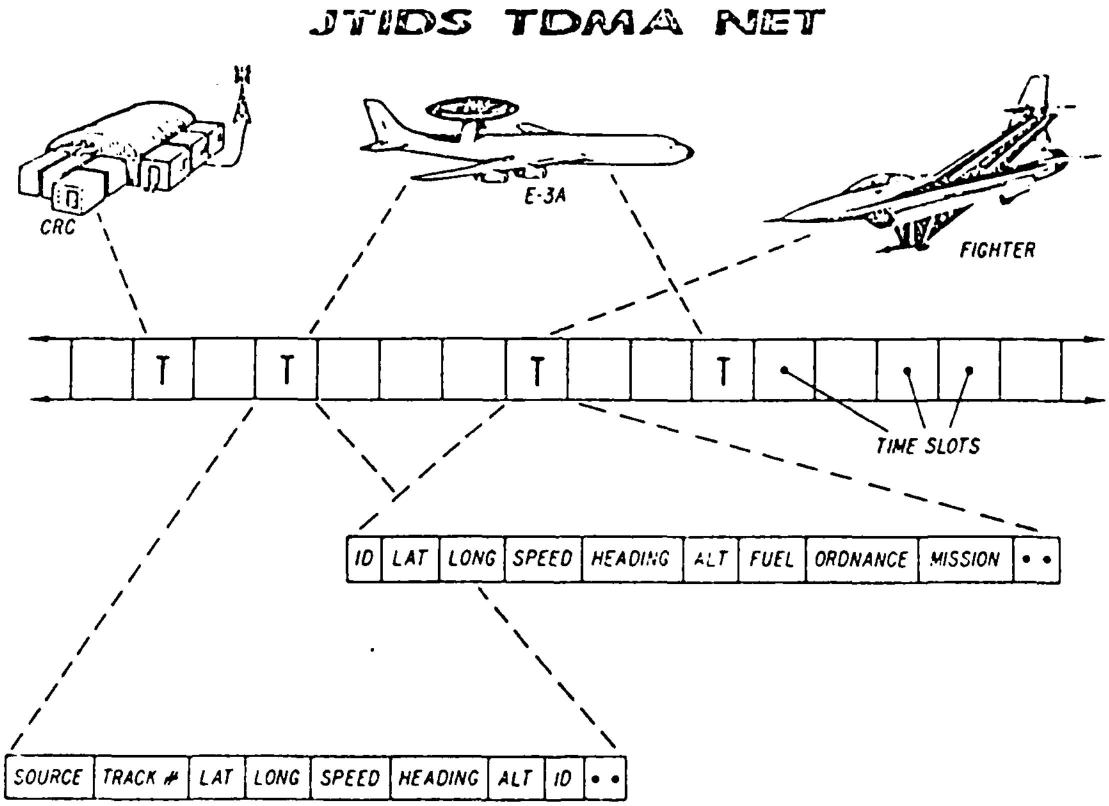

Figure 5. JTIDS TDMA NET (38:5)

Participating units can display JTIDS information visually through the use of their terminals. The display shown in Figure 6 is a typical video display which will eventually be installed in all F-15 and F-16 fighter aircraft. The pilot viewing the display is at the center of the presentation. The display shows symbols for friendly tracks as well as unfriendly tracks. In addition to the location of a target, other information, such as altitude, can be displayed. This would give the pilot a complete three dimensional view of airspace in which he is flying (38:13). To retrofit the terminal with its cockpit display into existing F-15s would cost the Air Force at least $359,000 per aircraft. When installed in the aircraft on the production line, the terminal would cost at least $233,000 per aircraft (38:32).

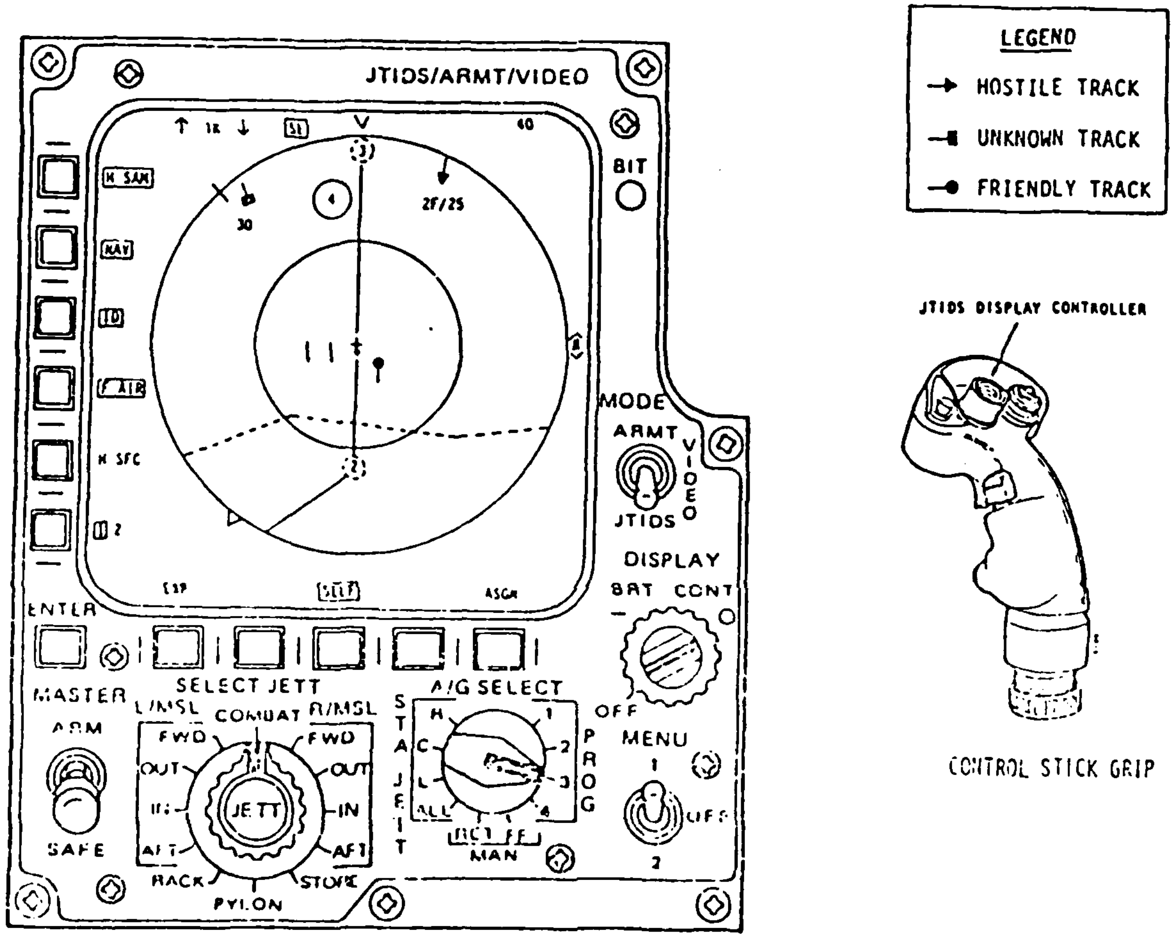

Figure 6. JTIDS Typical Situation Awareness Display (38:13)

JTIDS will be a jam resistant system. One message in each time slot can contain 225 bits of information. The information is encrypted and transmitted as a sequence of pulses. Each pulse is coded to represent five bits and spread over a frequency bandwidth of three megahertz (MHZ). The sequence of pulses is transmitted at a rate of nearly 77,000 per second, and each successive pulse is transmitted on a different carrier frequency. This combination of spreading and fast frequency hopping is the basis for JTIDS' jam resistance. JTIDS' jam resistance is further enhanced by transmitting the same five bits of information on two successive pulses for redundancy (38:6). Although these techniques will not make it impossible for the enemy to jam a JTIDS net, they will make it terribly difficult.

JTIDS will also be an interoperable system. Both the Air Force and the US Army will use the TDMA JTIDS system. Although the US Navy will use a slightly different JTIDS architecture, its mode includes the ability to communicate with Air Force and Army JTIDS terminals. Plans are underway to make JTIDS interoperable among NATO forces as well. Already the United Kingdom uses the same JTIDS architecture (TDMA) as the US Air Force. There is a NATO project group working on a standardized NATO system called Multifunctional Information Distribution Systems (MIDS) so that all NATO forces will have interoperability between different nations' versions of JTIDS (5:61).

But will JTIDS enable the pilot to perform his own air traffic control from the cockpit? It seems that, with the ability to display other aircraft locations and altitude in the cockpit in a meaningful manner, JTIDS does give the pilot the information he needs to separate himself from and sequence in with other aircraft to recover to a friendly base. The nodeless and jam resistant features of JTIDS add to its survivability and make it an attractive possibility to allow the Air Force to eliminate ground-based ATC radars and let the pilot do his own ATC from the cockpit. However, even with JTIDS there are limitations. First, as with the GPS, for JTIDS to replace the ground-based radars as a viable ATC system, every aircraft (US and NATO) will have to be outfitted with the JTIDS terminals and cockpit video displays. This means thousands of aircraft, from helicopters to cargo aircraft, will have to be retrofitted with the $359,000 version of JTIDS terminals! Obviously this would pose a severe financial burden. But even if we overcame the financial problem and outfitted every aircraft with JTIDS terminals, there would still be another problem. Aircraft returning from battle surely would have incurred battle damage which may include damage to their ability to transmit their location and altitude to other aircraft. This means that a pilot's cockpit display might not show a significant number of aircraft that are returning to the same base. Therefore, how would the pilot separate himself from and sequence himself in with aircraft he can neither see nor communicate with?

But there are other reasons why conducting ATC from the cockpit using JTIDS may not be technologically feasible. In Chapter Two, the analysis of the future wartime environment shows that landing bases will change rapidly and aircraft may need to land on unprepared strips at little known locations. Enemy aircraft may penetrate our initial air defenses and get through to our bases. Friendly aircraft will return from the battle with possible damage to their JTIDS equipment. In a cockpit-based ATC system using a nodeless JTIDS structure with no ground ATC, who will direct these aircraft to different bases to ensure that no one base is overloaded and aircraft do not run out of fuel while waiting to land? Also, the Army's SHORAD system will have to rely on information transmitted from every returning aircraft's JTIDS terminal to determine the location of friendly aircraft. This information is vital to the Army's ability to distinguish between friendly and enemy aircraft in its effort to provide a last line of defense against enemy air attack on our bases. But if friendly aircraft JTIDS terminals have battle damage, how will the Army determine their location and distinguish between them and enemy aircraft? Without the capability to do this, our air defenses may shoot down our own aircraft!

CONCLUSIONS

As a result of this analysis of the three most visible military navigation and tactical improvements, it seems that JTIDS provides the best possibility to give the pilot the information he needs to do his own ATC from the cockpit. The GPS, as designed, gives the pilot his location only--not the location of other aircraft, information absolutely necessary to separate and sequence himself. The Microwave Landing System has a similar limitation and is even more restrictive. Its coverage does not include a complete circle around the airport and therefore would not cover all aircraft that would be a factor for a pilot in the separation and sequencing functions of ATC. But JTIDS gives the JTIDS equipped pilot the location and altitude of other JTIDS equipped aircraft. However, even JTIDS has its limitations. The costs of installing a JTIDS terminal in every friendly aircraft may be prohibitive. The possibility that battle damage might destroy the JTIDS terminal without destroying the aircraft's flyability may bring disastrous results in a cockpit-based ATC system with no ground-based radar ATC. Therefore, though it is theoretically possible from a technological standpoint for a pilot to conduct his own ATC from the cockpit in a stable, peacetime environment, his attempt to control himself in a complex wartime scenario is not technologically feasible.

Chapter Four

HUMAN CONSIDERATIONS--IS IT HUMANLY POSSIBLE FOR THE PILOT TO DO HIS OWN ATC?

INTRODUCTION

But even with the technological capability, can the pilot perform his own separation and sequencing using information from a display in the cockpit while maintaining control of his aircraft as he attempts to land in a wartime environment? This study could find no studies directly concerned with this subject. Therefore, to analyze the human considerations of a cockpit-based ATC system the study assumes that the pilot workload in a cockpit-based ATC system in a wartime environment would be greater than pilot workload in the present ground-based system since the pilot would be responsible for his own separation and sequencing. With this assumption in mind, this chapter looks at pilot workload in the terminal area in the present system as well as the effect of such workload on flying safety in the present system. The chapter also addresses the mechanics of separation and sequencing by pilots in a cockpit-based ATC system while looking at the prominence of pilot-related human error, distraction, and channelized attention in terminal airspace surrounding an airport. Finally, the chapter concludes with some overall observations about human considerations of a cockpit-based ATC system.

PILOT WORKLOAD

The technology that makes a cockpit-based ATC system even thinkable is intended to decrease pilot workload. However, although advanced technology has apparently decreased some manual workload, it has really shifted the workload from manual to mental. According to Mr. Earl Wiener of the University of Miami in Florida who wrote in the Human Factors Society Journal in February 1985, advanced devices have to be monitored. Mr. Wiener writes, "Pilots complain of more programming, planning, sequencing, alternative selection, and more thinking" (29:75). Field studies by Mr. Wiener on the McDonnell-Douglas DC-9-80 program indicates pilots perceive some reduction in total workload due to automation of cockpit functions but much less than previously thought. Mr. Wiener found that pilots did not have any time to scan outside the cockpit for other aircraft because the automatic devices in the cockpit required so much attention (29:77). In a study of single pilot autopilot complexity documented in the Journal of Aircraft, Mr. H.P. Bergeron found that beyond a certain level of autopilot automation the pilot's workload levelled off rather than decreased because the pilot had to monitor the autopilot's control of the flight. The increased level of autopilot automation tended to take the pilot out of the aircraft control loop. The pilot became a manager of the autopilot function and was more likely to lose track of where he was on an approach to land (2:705). Unless something is done to stop this trend, the problem will exist in the US Air Force as well. According to Mr. Bill Sweetman, who wrote about the Air Force's Advanced Tactical Fighter in Interavia, "There is plenty of information available; in fact, far too much for the pilot of a single seat fighter, if the avionics system and the cockpit displays follow today's pattern" (26:606).

Many other studies show that this mental workload is a significant factor in the military terminal area when a pilot is trying to safely land an aircraft. Mr. Chiharu Sekiguchi documented a study on mental workload under flight conditions in Aviation, Space, and Environmental Medicine. He used heart rate variability as an index of mental stress while studying Japanese Air Force student pilots in T-33 and F-86 aircraft. His study concluded that the takeoff and landing phases of flight gave the pilot the strongest mental stress. Sekiguchi said, "...the mean heart rate increased prominently in the takeoff and land phases, which were considered as both high interpretative actions and high emotional stress situations" (23:925). A 1981 US Air Force study by William L. Welde of the Aerospace Medical Research Laboratory at Wright Patterson Air Force Base, Ohio concentrated on cognitive workload and information transfer. The overall objective of Welde's study was to perform a definitive assessment of the pilot in a single seat aircraft. Welde used the A-7D fighter aircraft under conditions that included three miles visibility, solid clouds at 1000 feet, and night. His study evaluated pilot workload in five mission segments that included approach and landing. His study concluded that the approach and landing phase had the greatest possibility for pilot performance error due to its required activities and procedures (39:96). Dr. William F. Storm and Capt. John T. Merrifield of the USAF School of Aerospace Medicine at Brooks Air Force Base, Texas conducted a study in 1980 on aircrew fatigue and workload in four-man (five-man normal) C-5A crews performing typical long-range transport missions. The study was done to evaluate the effect of eliminating the navigator's position due to the installation of a triple Inertial Navigation System. Some navigators' duties were assigned to the pilots and others to the engineers. The study found that the highest workload scores were consistently reported in association with landings and takeoffs (32:10). The study concluded, "The operational conditions of wartime should be considered in any decision to remove the navigator from the C5A crew complement. The availability of an additional skilled crewmember provides more performance insurance during periods of extreme stress and fatigue such as encountered during wartime or serious emergencies" (32:19).

But what does all this workload have to do with the pilot performing his own air traffic control functions from the cockpit instead of relying on a ground-based controller? In view of the high workload in the terminal area near the airport, can the pilot separate himself from and sequence himself with other aircraft? The experts say no. Dr. James Miller, a research physiologist with the USAF School of Aerospace Medicine at Brooks Air Force Base, Texas commented on the idea of military pilots performing their own ATC from the cockpit, "This is a dangerous idea. There is so much workload now that having the pilot do ATC would max out the pilot" (57). Mr. Cy Crites, Chief of the Human Factors Branch of the 6520th Test Group at Edwards Air Force Base, California said, "I don't think the pilot can separate and sequence himself in with other aircraft. Pilots are so close to saturation now that adding this burden probably would be insurmountable" (53). These experts were referring to pilot workload in the current peacetime environment. When one adds the highly stressful and fatiguing conditions of war and bad weather in Europe to the current workload of the pilot in the terminal area one can imagine the unbearable workload the pilot would encounter if he also had to separate and sequence himself in with many other aircraft trying to land at the same base. In addition, having to contend with a possible emergency due to battle damage and having to perform his own ATC from the cockpit may prove to be an insurmountable workload for the pilot. Therefore, although there have been no direct studies on the pilot performing his own ATC, evidence from other workload studies point to the conclusion that the pilot cannot perform his own ATC from the cockpit because the workload would be too much.

SAFETY

But what effect might this workload in the terminal area have on the pilot? What are the consequences for flying safety of placing a high workload on the pilot possibly through a cockpit-based ATC system? Well, the consequences of high workload on the pilot can be disastrous and result in accidents such as "controlled flight into terrain." Jeffrey Rhodes, who interviewed senior officers at the Air Force Inspection and Safety Center at Norton Air Force Base, California, wrote,

> The causes leading to controlled flight into terrain (CFIT) stem mostly from the operator of the airplane and the man/machine interface. The predominant factor in these mishaps is channelized attention on something

other than terrain avoidance, although spatial disorientation (SDO) is another contributing cause. Fatigue, distraction, task saturation, and mission stress are the other major elements. In a majority of accidents, at least two of these factors are present (21:82).

In a cockpit-based ATC environment, the "man/machine" interface would be extremely important since the pilot would almost certainly be constantly having to scan a display of other air traffic in his cockpit. Yet it is this interface that is already a theme in many aircraft accidents. Mr. Wiener wrote in his Human Factors Society Journal article that after accidents in the 1950s and 1960s, aircraft designers tried to eliminate accidents by eliminating the possibility of pilot error through aircraft automation. But according to Wiener there were flaws with this reasoning. The devices themselves had to be monitored and operated by humans whose error they were designed to avoid. Therefore, the devices had the potential for generating errors that could result in accidents. In fact, one such human error according to Wiener and the International Civil Aviation Organization may have led a crewmember to put in the wrong Inertial Navigation System coordinates that led to the KAL 007 disaster (29:87). Wiener's findings support William Schultz' findings who wrote about problems of the cockpit environment for a NATO Advisory Group for Aerospace Research and Development Symposium in Amsterdam, Netherlands in 1968. Schultz wrote,

> ...for a crew to take action as a result of a display input, they must be looking at the display at the time, the display must give a correct indication, and the display reading must be correctly interpreted. In some studies, it has been found that pilots make reading and interpretation errors in almost any type of aircraft and all flight conditions (22:6-3).

Richard Jensen supported Wiener and Schultz' findings in a 1982 article in the Human Factors Society Journal. He said that an analysis of accident statistics revealed that over 50 percent of pilot caused civil aviation accident fatalities are the result of faulty pilot judgement. He also said that technological advances that were designed to ease much of the pilot's burden for aircraft control have not greatly eased the pilot's decision making workload. In many cases, Jensen said, the advances only created demands for higher levels of skill, knowledge, and judgement (8:61).

Certainly pilot success in a cockpit-based ATC system will require extremely high levels of skill, knowledge, and judgement. To separate himself from and sequence himself in with other aircraft safely while maintaining aircraft control will require error-free performance on the part of the pilot. For example, when a pilot arrives in a block of airspace surrounding a base, he may arrive at the same time as other aircraft. After realizing, by scanning his cockpit display, that other aircraft arrived at the same time, the pilot must first decide who will go first. What will the sequence be? Of course, one pilot cannot make this decision by himself. He will have to cooperate with the other pilots to decide who will go first, second, third, and so on since there will be no one on the ground to set the sequence. Of course, the pilots will have to make this judgement quickly since their aircraft are traveling at high speeds toward the same runway.

The next task for the pilot will be separation. To maintain adequate separation, the pilot will have to know the types of all the other aircraft trying to land at the same base. For example, if a C-5 is in the pattern, a fighter pilot should stay far enough away that he will not get caught in the C-5's wake turbulence. Again, the pilot will have to know and apply separation criteria quickly while constantly scanning his cockpit display because he and the other pilots are travelling at very high speeds and getting closer to the runway and each other every minute. Even in perfect conditions scanning the cockpit's ATC display and maintaining aircraft control while making all the right decisions in cooperation with all the other pilots landing on the same runway will obviously demand an extremely high level of skill, knowledge, and judgement. But what will happen when unplanned factors enter the picture? What if there are several emergencies at once and all these aircraft are trying to land on the same runway? What if this occurs in bad weather which is so common throughout Europe? In bad weather and at night pilots will have to rely totally on the information they derive from their cockpit displays. Even worse, what if the setting is wartime in Europe? Then, there is a possibility of having many pilots trying to land on an unfamiliar runway in bad weather, with normal emergencies, battle damage, and an enemy threat with which to contend. Surely this situation will require an extraordinarily high level of skill, knowledge, and judgement if all pilots intend to land safely in a cockpit-based ATC system.

Yet statistics and examples of aircraft accidents and incidents show that many accidents and near collisions caused by pilot-related human factors, error, and bad judgement occur especially in terminal airspace surrounding military bases--the same airspace where a cockpit-based ATC system for military pilots would operate. In fact, according to the MAC Flyer in June 1985, "human error", "approach", and "landing", are phrases frequently used in describing causes of aircraft accidents. The magazine said 85 percent of aircraft accidents involve human error as a contributing factor and about 50 percent of all accidents occur in the approach and landing phase (28:17). According to the Air Force Safety and Inspection Center at Norton Air Force Base, California, more than 50 percent of the 81 operations-related aircraft accidents in terminal airspace between 1980 and 1985 were caused by pilot-related channelized attention, spatial disorientation, fatigue, and task saturation (48). In September 1984, Major James Majors of the Air Force School of Aerospace Medicine at Brooks Air Force Base, Texas documented a human factors study on C-5 pilots after two stall-related near mishap incidents involving C-5 aircraft occurred. He used questionnaires and interviews to collect data from 34 C-5 pilots. A majority of the surveyed pilots indicated various problems (probably fatigue-related) with channelized attention and distraction during critical phases of flight such as approach and landing (36:10). The following situations taken from the June 1983 Flying Safety and December 1984 MAC Flyer magazines illustrate the prominence of human error caused by fatigue, distraction, or channelized attention in terminal airspace in aircraft incidents:

> Situation #1 - Two aircraft trying to separate themselves and land visually reported over the same geographical point. One pilot started scanning the airspace outside his cockpit and nearly lost control of his aircraft.
>
> Cause - At a time when the primary duties of the pilots should have been concentrated on landing their aircraft, they spent too much time searching airspace for each other.
>
> Situation #2 - A pilot who had flown for 20 years was returning home after a long mission. He descended below a routine 5000 feet crossing restriction without clearance and nearly hit another aircraft.
>
> Cause - Fatigue, rush to land after a long, tough mission (1:23).
>
> Situation #3 - The C-130 crew was returning home after a normal mission. In terminal airspace, the aircrew reported an overheated engine which developed into a fire. The crew flew the aircraft into the ground.
>
> Cause - The crew's attention became channelized on the emergency, became disoriented, failed to maintain aircraft control and flew the aircraft into the ground. (6:8)

But what do these statistics and incidents have to do with a cockpit-based ATC system? Certainly these incidents don't happen every day at every base. They don't illustrate the abilities of all our pilots. But they do point to high risk and the necessity for alertness in the terminal airspace surrounding any airport. They also show the prominence of human error caused by fatigue and channelized attention in aircraft accidents and incidents. They show that the possibility for some pilots to make mistakes because of workload or channelized attention when trying to land in terminal airspace does exist. But the study has already shown that the tolerance for error in a cockpit-based ATC system is practically nil. In fact, it has shown that the pilot may have to spend a considerable amount of time scanning his cockpit ATC situation display in an effort to separate and sequence himself with other aircraft. Yet the statistics and incidents described by this study show that once the pilot is overloaded or fixates his attention on one thing, he increases the chances for an accident or incident. Therefore, a cockpit-based ATC system significantly increases the potential for loss of lives and multi-million dollar aircraft in peacetime and would exacerbate these losses in a wartime environment.

CONCLUSIONS

An examination of the human considerations of pilot workload and flying safety do not favorably recommend a cockpit-based ATC system. The workload of a pilot trying to separate himself from and sequence himself in with other aircraft trying to land on the same runway and safely control the aircraft would be insurmountable. This workload might have disastrous effects on the ability of the pilot to safely control his aircraft and might result in fatal crashes. To perform the ATC functions of separation and sequencing the pilot would have to use unparalleled skill, knowledge, and judgement to constantly scan his cockpit display of other traffic trying to land on the same runway. But this constant attention on the display and on separation and sequencing could easily divert his attention away from aircraft control in the airspace surrounding a base, already a high risk area for aircraft accidents and incidents. Fixated attention on the cockpit ATC display could therefore cause the pilot to err in his aircraft control tasks and ultimately result in loss of control and a fatal crash. In conclusion, from a standpoint of workload and flying safety, this study does not recommend a cockpit-based ATC system as a substitute for the present ground-based radar system.

Chapter Five

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This study has looked at the possibility of a cockpit-based ATC system by examining the requirement for ATC, the present ground-based ATC system, technology available to establish a cockpit-based ATC system, and the human considerations of a cockpit-based system. The requirement for military ATC is to separate and sequence aircraft returning from wartime missions so they can safely land and later return to the fight. The wartime environment will be a dynamic environment with widespread electronic and physical threats from the enemy probably against our aircraft, ground radars, and bases. Aircraft will possess high technology, they will be stealthy, and they may need to land at a different base from which they departed upon return from the battle.

Our present system is hardly equipped to cope in the future wartime environment although it has some major attractions as an ATC system. The system consists of radars of Korean War vintage more than 30 years old and radars that will soon be 20 years old. The system has a low survivability probability. Its radars can easily be jammed and they are located close to runways, thereby exposing them to collateral damage from attacks on the runway. Their signals and location also help enemy aircraft pinpoint concentrations of friendly aircraft. One of the present system's major attractions as a wartime ATC system is that radar is an independent system. It can paint all aircraft within its range because its primary radar does not depend on any equipment in the aircraft. Therefore, it can recover aircraft with battle damage. Its second major attraction is that it provides an immediate source of real time aircraft information to the Army's Short Range Air Defense (SHORAD) System so the local Army air defense system won't shoot down friendly aircraft. However, aside from these two capabilities, the present system will not be able to cope with a future war.

But it appears at first that new aircraft electronic technology might come to the rescue and make a cockpit-based ATC system possible, thereby eliminating the need for the present system's ground-based radars. Although theoretically possible from a technological viewpoint, however, a cockpit-based ATC system is not feasible. Neither the Global Positioning System nor the Microwave Landing System offer attractive possibilities. Both would require highly expensive modifications because neither is designed for ATC. Even the Joint Tactical Information Distribution System (JTIDS), which holds out the greatest possibility for a cockpit-based system, has major liabilities. First, to establish a cockpit-based ATC system with JTIDS would mean putting a JTIDS terminal in perhaps thousands of aircraft that may need to use the new ATC system. At a cost of more than $300,000 per terminal, this would be much more expensive than buying 25 more TPN-19 ground radars at $4.6 million per radar. Even if every aircraft were outfitted with a JTIDS terminal, every terminal would have to remain completely operational through bad weather and enemy threats for a cockpit-based ATC system to work. Finally, none of the new technology, JTIDS included, provides for giving complete and accurate real time information to the Army's SHORAD system. Therefore, the Army would have severe problems distinguishing between enemy and friendly aircraft with its air defense weapons.

The outlook for a cockpit-based ATC system appears bleak from a human considerations viewpoint also. Pilot workload in a cockpit-based system appears insurmountable. Although apparent workload may be decreased, with automation, mental workload already is high for a pilot in the terminal area. Experts say adding the ATC responsibilities of separation and sequencing to this high workload would be dangerous in peacetime and worse in wartime. The impact of this workload on flying safety would be disastrous. With the pilot already flying in airspace where most accidents occur, the pilot might be placed at even higher risk when he has to constantly scan a cockpit display of moving targets to separate and sequence himself with other aircraft flying toward the same runway while attempting to comply with SHORAD manuever requirements. If one adds the risks of channelized attention on the cockpit display to the high possibility of the pilot having to contend with battle damage, injury, the enemy threat, and bad weather, one has the ingredients for disaster. Finally, the chances of disastrous error would be extremely high when one adds to all these ingredients a situation in which several aircraft arrive in the airspace surrounding the base at the same time and pilots have to cooperatively establish a sequence. After all, there would be no unbiased arbitrator on the ground to establish the sequence.

In conclusion, because of technological and human considerations, a cockpit-based ATC system would not be a sound replacement to eliminate the shortcomings of the present ATC system in war. The USAF will continue to need a ground-based radar ATC system in the year 2000.

RECOMMENDATIONS

For the recommendations it is important to understand several points. First, there is a need for an unbiased arbitrator to determine the sequence and separation for aircraft attempting to land on the same runway. In the words of Mr. Siegbert B. Poritzky, Director of the FAA's Office of Systems Engineering Management: "...most experts say that some centralized form of ground control will always be needed. There must still be a traffic cop" (17:52).

The second point is that one must remember what the pilot's mission is. His or her mission is to drop bombs, strafe targets, shoot down other aircraft, ferry vital cargo between bases, and rescue downed pilots. The pilot's mission is not to perform all functions of air traffic control.

However, this does not mean the pilot should not perform any ATC functions. Even without the future's technological innovations, controllers allow pilots to perform some minimal separation tasks. For example, when the weather is good and the pilot's workload permits, the controller can allow the pilot to separate himself from another aircraft he has in sight when they are both landing on the same runway. However, the controller has already set the sequence and told the pilots the order in which they will be landing in this procedure called a visual approach. The controller must also continue to monitor the aircraft and intervene if a dangerous situation develops (44:117). Controllers use this procedure to expedite aircraft landings since pilots may use less than the normal radar separation a controller must apply.

If future cockpit displays give pilots the position of other aircraft in the terminal area, the ground-based radar controller might then have the capability to apply procedures similar to the visual approach in bad weather. In other words, when pilot workload permits and two aircraft approaching the same runway see each other on their cockpit displays, the controller could sequence them and then allow them to separate themselves until landing using their cockpit displays. Although the controller would have to monitor a dangerous situation, the pilots would be responsible for separation. As a result, this sharing of ATC functions, brought about by future technology could expedite air traffic without impairing the pilot's mission or sacrifice the safety of having a ground-based arbitrator.

Therefore, in view of the advantages and disadvantages of ground-based radar presented in the conclusions and the points made above, the study makes the following recommendations:

1. Air Force should not pursue research and development of a cockpit-based ATC system.

2. The Air Force should pursue research and development of a new highly-mobile, long-range ATC radar that will be highly jam and electro magnetic pulse (EMP) resistant with an initial operational capability in the mid-1990s. The radar's secondary mode should be fully interoperable with our NATO allies' aircraft systems.

3. When the radar is fully operational, it should be employed in remote rear areas dispersed from forward operated bases to heighten survivability. Its location need not be fixed. As long as it is within range of the bases it controls, the radar should be able to deploy anywhere on a moment's notice.

4. Air Force should research and develop procedures to use future cockpit technology for the benefit of the pilot and controller. Controllers might be able to better expedite traffic in bad weather and war for those aircraft that are properly equipped with cockpit displays of other aircraft in the terminal area.

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